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Application of Gordon-Schaefer Model to evaluate bioeconomic and management aspects of *Scomberomorus sinensis* fishery in Shandong, China

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Commercial marine fishery resources of China are generally considered to be overexploited. This condition may lead to the extinction of fishery resources and overcapitalization of the fishing fleets. Therefore, this study simultaneously evaluates the stock status and economic efficiency of a very important commercial marine fishery resource, i.e., *Scomberomorus sinensis* of Shandong, China by using a data for a period between 2003 and 2016. It employs a famous fishery surplus production model, *viz*., Gordon-Schaefer Model (GS-model) to compute various harvest levels and their corresponding effort levels. These levels or reference points (RPs) were estimated for three exploitation states, i.e., maximum sustainable yield (MSY), maximum economic yield (MEY), and open access yield (OAE). At MSY the harvest, effort, and revenue were calculated as H_{MSY} = 185357 metric tons (MT), E_{MSY} = 35624 and 1.80 billion RMB. On the other hand, the same parameters computed at MEY remained H_{MEY} = 137177 MT, E_{MEY} = 17462 and 5.01 billion RMB, in that order. Harvest and corresponding effort levels at OAE were computed as H_{OAY} = 185285 MT and 34924, respectively. It is also found that despite controlling the effort levels, CPUE is showing a decreasing trend in the past few years which may be an outcome of overexploitation. Moreover, the revenue generated at MEY is about three times greater than the revenue generated at MSY. This increased revenue can be achieved by further lowering the effort levels. Thus, there is a dire need to make and implement such policies which can conserve *S. sinensis* fishery resource and increase the revenue at the same time. Therefore, further comprehensive studies are needed in this regard as this study is just a preliminary work.

[Keywords: China, Gordon-Schaefer model, MEY, MSY, OAY, *Scomberomorus sinensis*]

Introduction

The classical fisheries economics combines fish biology, ecology, and economic aspects of the fishery[1-5]. Conversely, its modern version has an additional capacity of understanding the complex impact of overcapacity and overexploitation on marine fisheries, which are affected by a change in the coastal system, absence of real fishing policies, and natural variations[6]. Fisheries management encompasses industry, resources, and trade involving economics[7]. Thus, fisheries economics and management are inter-related. In essence, this science carries out economic analysis to study profit by using cost and price data and help to identify sustainable harvest levels. These harvest levels are the points, which promise high economic efficiency along with stability of the fish stock[5]. For the sake of fisheries management, two reference points (RPs) are used conventionally, i.e., maximum sustainable yield (MSY) and maximum economic yield (MEY). As their name indicates, MSY is used for the biological conservation of fish stock, whereas, MEY is used to maximize fishery resource rent. Hence, both of these reference points have different performance objectives. However, in the absence of fisheries management, another RP named as open access equilibrium (OAE) exists, which may lead to the tragedy of the commons[8]. On the other hand, some researchers argue that at MSY fishing industry can provide more economic output as compared to MEY. They claim that the concept of MEY belongs to individual fishing fleets and does not include the whole fishing industry. In contrast to this, MSY is a better reference point for the whole fishing industry[9].

Economics of fisheries and its catch is different at all of these RPs. At OAE or MSY, the catch is lower as compared to MEY and on the other hand, the cost is higher. In the science of fisheries economics, MEY is preferred reference point for fisheries management because at this point resource rent is maximum.

However, OAE, MSY or MEY is perused depending upon the fisheries management advice[10]. In order to ascertain these harvest levels, surplus production models (SPMs) are often employed. Thus, fisheries can be managed with the use of SPMs, particularly, when only time series catch and effort statistics are recorded[11]. The main purpose of the use of SPMs is to determine the optimum effort levels, which are essential to produce the MSY without affecting the long-term productivity of the fish stock[12]. The application of these SPMs in fisheries economics is also confirmed from previously published literature[13]. Most introductory books on fisheries economics explain the fisheries problem using various forms of the Gordon-Schaefer Model (GS-model)[3,14-16].

China is an East Asian coastal country. Its marine waters belong to the Bohai Sea, the Yellow Sea, the East China Sea, and the South China Sea[17]. Fisheries play a very important role in the economic development of China[18]. It is reported that six major groups of fishery resources, *viz*., jellyfish, seaweed, shellfish, cephalopods, crustaceans, and finfish are commercially hunted. The Yellow Sea and the Bohai Sea contribute significantly in the commercial capture production, around 31 %, of fishery resources[19]. In 2004, 2.7 million metric tons (MT) of fishery resources were caught from these Seas[20]. These seas are separated by the peninsula of the Shandong Province[21]. It is a leading province of China in terms of fisheries capture production[22]. According to an estimate, about 946 fishing villages, in which 580000 fishermen reside, are located in this province. Moreover, the fish processing industry and fish market are also located in various cities of Shandong such as Qingdao and Yantai[20].

Chinese seerfish, *Scomberomorus sinensis* (Lacepede 1800), is among the major fishery resources unloaded on the landing sites along the coast of Shandong[23]. This ray-finned fish belongs to class Actinopterygii and genus Scomberomorus[24]. It is found in diverse aquatic habitats such as freshwater, marine, brackish etc.[25]. It has high economic value in the Chinese market and brings huge profits to the fishermen. It is utilized in various forms for example dried, fresh, smoked, boiled, fried, and baked[26]. The reported capture production of this fishery resource from Shandong in 2003 and 2016 was 170389 MT and 168456 MT, respectively[23]. This indicates that the recently capture production of this important fishery resource after fluctuations has started to decline. Moreover, several studies declare that Chinese marine fishing fleets are overcapitalized[27]. Thus, it is essential to understand bioeconomic and management aspects of this important fishery resource. However, the previously published literature is devoid of such studies. This study is the first attempt to comprehensively describe the bioeconomic and management aspects of a very important fishery resource, viz., *S. sinensis*. It employs a famous fishery model known as the GS-model applied to data collected from Shandong, China. This study aims to estimate various harvest levels along with their corresponding effort levels to fully understand the mechanisms of ongoing bioeconomic, cost and revenue, and management, exploitation status, implications. It is expected that this study will give direction to understand and manage *S. sinensis* fishery resource biologically as well as economically.

Materials and Methods

Data acquisition

In order to conduct this study, desk, as well as field study, was done. Data was obtained from multiple sources. Firstly, an extensive review of the literature was done related to the economics of commercial marine fisheries. For the literature review, various online available sources such as research papers, research reports, opinion articles, review articles, and online websites were explored. The principals of fisheries economics were thoroughly probed into and perceived. Secondly, field surveys were conducted at the landings sites located at Loashan and Huangdao districts of Qingdao, Shandong, China. Fishermen working on these dock stations were interviewed and fisheries bioeconomics data was obtained in the form of a questionnaire. In total, twenty-three questionnaires were filled by fishermen, nine belonged to Laoshan district and fourteen belonged to Hunagdao district of Qingdao, Shandong, China. From the collected data through questionnaire, the cost per unit effort (c) and price per unit harvest (q) was assessed. Thirdly, fishery catch and effort statistics, 2003-2016, related to commercial marine fishery were obtained from published Fisheries Yearbooks of China[23].

Data analysis

In this study, the GS-model[28-29] is employed according to the description of Habib *et al.*[30] to access the bioeconomic implications of the commercial marine fishery of *S. sinensis* in Shandong, China. This model relies on logistic growth of the fish stock and is represented as follows:

$$F\left(X\right) = rX\left(1 - \frac{X}{K}\right) \quad \ldots(1)$$

Where *F(X)*, K, *X*, and *r* represent surplus biomass growth per unit of time, carrying capacity, stock biomass and intrinsic growth rate, in that order. The parabolic curve, as a function of *X*, presented in Figure 1 is represented by this equation. *H* (harvest rate) was measured in biomass catch per unit time (*E*, *X*). It was computed by using Schaefer catch function as given below.

$$H\left(E, X\right) = qEX \quad \ldots(2)$$

Where, *q* and *E* are catchability coefficient and fishing effort, respectively. Under sustainable yield conditions equation, 1 and 2 should be equal or when the rate of change of biomass is equal to $\frac{dx}{dt} = F(X) - H(E, X) = 0$. Solving this condition results in the following equation:

$$X = K\left(1 - \frac{qE}{r}\right) \quad \ldots(3)$$

Where, *X* represents biomass at equilibrium. Catch equation for long-term exploitation of fishery resource can be obtained as follows:

$$H(E) = qKE\left(1 - \frac{qE}{r}\right) == qKE - \frac{q^2KE^2}{r} \quad \ldots(4)$$

Furthermore, the relationship between CPUE (catch per unit effort) and effort can be obtained by both sides of equation 4 with effort (*E*).

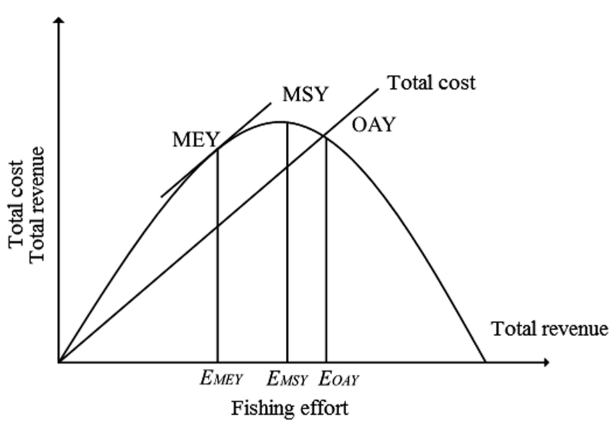

Fig. 1 — Gordon-Schaefer Model

$$CPUE = \frac{H}{E} = qK - \frac{q^2KE}{r} \quad \ldots(5)$$

By using the above equation and putting TR (total revenue), at equilibrium as a function of standardized effort, in it following equation is obtained.

$$TR(E) = p.H(E) \quad \ldots(6)$$

Where, *p* denotes constant price per unit harvest. Likewise, TC (total cost) of fishing effort is represented as follows:

$$TC(E) = c.E \quad \ldots(7)$$

In this mathematical equation, *c* (unit cost of effort) is composed of three different types of costs, i.e., fixed, variable, and opportunity cost. Fixed costs include the price of a trawler, depreciation, and license fee. On the other hand, variable costs incur bait, fuel, beverages, food, etc. Opportunity costs are the estimated costs by assuming the next best possible economic activity such as capital investment, regional fisheries, alternative employment, etc.[12].

TR (resource rent), at equilibrium, can be represented as follows:

$$\prod(E) = TR(E) - TC(E) \quad \ldots(8)$$

Regression analysis was done on CPUE. By assuming AR (average revenue) and MC (marginal cost) following equation is obtained.

$$\frac{pH}{E} = c \qquad \frac{H}{E} = \frac{c}{p} \quad \ldots(9)$$

Open access stock biomass is represented as

$$X_{\infty} = \frac{c}{qp} \quad \ldots(10)$$

Equation 4 in terms of long-term harvest function can be expressed as follows:

$$H(E) = aE + bE^2 \quad \ldots(11)$$

Values of *a* and *b* are obtained by the regression analysis of CPUE. On the other hand, *K* and *r* were calculated as follows:

$$K = \frac{a}{q} \quad \ldots(12)$$

$$r = \left(\frac{-aq}{b}\right) \quad \ldots(13)$$

So, $CPUE = \frac{H}{E}$ can be expressed as follows:

$$CPUE = a + bE \quad \ldots(14)$$

Equation 11 was employed to get E_{MSY} by taking partial derivation of harvest (H) regarding fishing effort (E) and setting it equal to zero.

$$E_{MSY} = \left(\frac{-a}{2b}\right) \quad \ldots(15)$$

Thus, $MSY = \left(\frac{-a^2}{4b}\right) \quad \ldots(16)$

At open access equilibrium, E_{OAY} can be obtained by applying the GS-model as follow.

$$E_{OAY} = \left(\frac{c/p - a}{b}\right) \quad \ldots(17)$$

$\prod_{MEY}$ (maximum economic yield) can be computed at a less total fishing effort, since positive economic rent is only obtainable at effort levels lower than E_{OAY}. By using equation 8, MEY was at the profit-maximizing level of effort which is represented as follows.

$\prod(E) = 0$ or $\frac{dTR(E)}{dE} = \frac{dTC(E)}{dE}$, so E_{MEY} is:

$$E_{MEY} = \left(\frac{c/p - a}{2b}\right) \quad (18)$$

In order to computed *q* (catchability coefficient), CEDA (catch and effort data analysis) was employed. For this purpose, catch and effort statistics of *S. sinensis* were analyzed by using an IP (initial proportion) of 0.8.

Results

In this study, the published catch statistics, 2003-2016, of *S. sinensis* fishery in Shandong, China, presented in Figure 2, were analyzed to know their exploitation status and economic performance. Maximum, minimum and average catch of *S. sinensis* during the study period was observed as 207430 MT (2007), 165151 MT (2015) and 180137 MT per year, respectively. On the other hand, maximum and minimum effort levels were recorded in 2010 (44808 MT) and 2012 (36081 MT), correspondingly. The obtained results indicate that computed CPUE fluctuated between 5.13 and 3.81. During the last three years of the study, CPUE has decreased from 4.13 (2014) to 3.99 (2016) as represented by Figure 3. The values of *a* and *b* were computed as 10.40 and -0.00015, respectively. These values were obtained by applying regression analysis of CPUE on corresponding effort level. Standard error values for these parameters remained 1.45 and 0.000035, in that order. The obtained R^2 value was 0.552, which represents variation, almost 50 %, in the CPUE data (Table 1). The values of *K* (47955056 MT) and *r* (0.015) were computed by using the values of *a* (10.40), *b* (-0.00015), and *q* (2.17E-07). Equations 12 and 13 were employed for this purpose.

The purpose of employing bioeconomic model, the GS-model, was to compute very important three kinds of fishery parameters, i.e., various harvest levels (H_{MSY}, H_{MEY}, and H_{OAY}), various effort levels corresponding to harvest levels (E_{MSY}, E_{MEY} and E_{OAY}) and economic rent ($\prod_{MSY}$ and $\prod_{MEY}$). Harvest

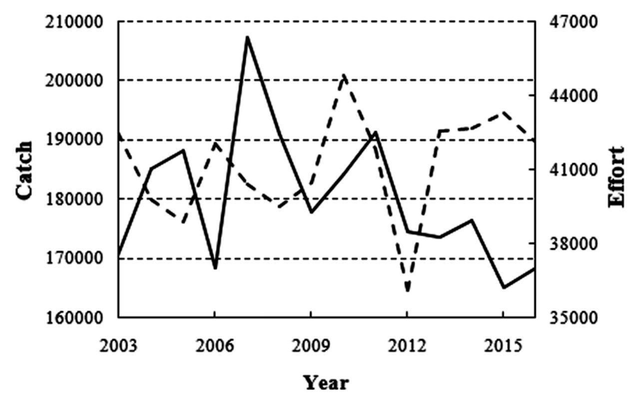

Fig. 2 — Catch (straight line) and effort (dotted line) statistics of *S. sinensis* fishery in Shandong, China (2003-2016). Note: Catch is in MT whereas effort is in the form of fishing boats

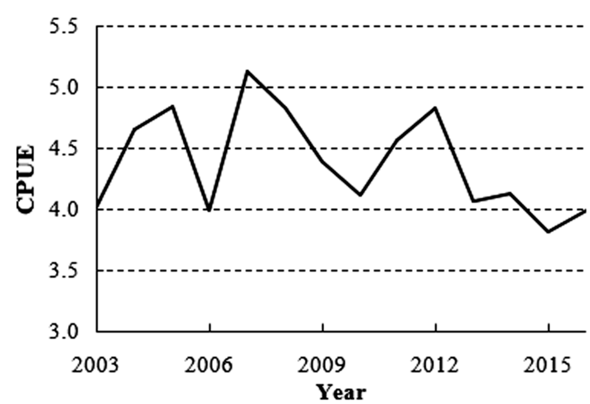

Fig. 3 — Computed CPUE for *S. sinensis* fishery in Shandong, China (2003-2016)

levels were estimated by putting values of *a* and *b* in equation 11, whereas, effort levels were computed by using equations 15, 17, and 18, correspondingly. In order to estimate economic rent, equation 8 was employed. Obtained values of harvest, effort, and economic rent are presented in Table 2. Estimated values of H_{MSY}, H_{MEY}, and H_{OAY} remained at 185357 MT, 137177 MT and 185285 MT, in that order. The lowest and the highest bounds of these harvest levels were obtained by using 95 % confidence interval and were estimated at 59368 MT – 668569 MT, 27382 MT – 566584 MT and 46364 MT – 636542 MT, correspondingly. On the other hand, E_{MSY}, E_{MEY}, and E_{OAY} values were computed at 35624, 17462 and 34924, respectively. The lowest and the highest bounds of these effort levels were estimated, by using a 95 % confidence interval, like 16427 – 98435, 4369 – 59990 and 8739 – 119979, in that order. At E_{MSY}, estimated values of TR and TC were 16263206642 RMB and 14463401568 RMB, correspondingly. The difference between TR and TC is the economic rent at MSY ($\prod_{MSY}$) which is 1799805074 RMB. Similarly, at E_{MEY}, computed values of TR and TC remained 13047512629 RMB and 8032013542 RMB, respectively. Thus, the estimated value of the economic rent at MEY ($\prod_{MEY}$), difference between TR and TC is 5015499087 RMB.

Estimates on the cost per unit effort and price per unit harvest are presented in Table 3. Data presented in Table 3 was obtained from the survey. The cost per unit effort (406000 RMB per trawl per year) was estimated by using three different types of costs per year, *viz*., fixed cost, variable cost and opportunity cost. Fixed cost (132000 RMB) was obtained by adding the costs of the average price of a trawler/gillnetter (125000 RMB), depreciation (5000 RMB) and license fee (2000 RMB). On the other hand, variable costs (250000 RMB) included fuel expenses (160000 RMB), labor expenses (75000 RMB) and food expenses (15000 RMB). It is

Table 1 — Regression analysis of CPUE on corresponding effort level of *S. sinensis* fishery in Shandong, China (2003-2016)

Parameters	Coefficients	Standard Error	Lower 95%	Upper 95%
a	10.40	1.45	7.22	13.58
b	-0.00015	0.000035	-0.00022	-0.000069

* Adjusted R^2 = 0.552

Table 2 — Harvest, effort and economic rent estimates of maximum sustainable, economic and open access yield of *S. sinensis* fishery in Shandong, China (2003-2016)

H_{MSY} (MT)	E_{MSY}	$\prod_{MSY}$ (Billion RMB)	H_{MEY} (MT)	E_{MEY}	$\prod_{MEY}$ (Billion RMB)	H_{OAY} (MT)	E_{OAY}
185357 *(59368 – 668569)	35624 (16427– 98435)	1.80	137177 *(27382 – 566584)	17462 *(4369– 59990)	5.01	185285 *(46364 – 636542)	34924 *(8739 – 119979)

Table 3 — Cost per unit effort (c) and price per unit harvest *S. sinensis* fishery in Shandong, China

COST PER UNIT EFFORT	FIXED COST	
	Average price of a trawler/gillnetter	125000
	Depreciation	5000
	License Fee	2000
	TOTAL FIXED COST PER ANNUM	132000
	VARIABLE COST	
	TOTAL VARIABLE COST PER ANNUM	250000
	OPPORTUNITY COST	
	Minimum wages of labor/month	4000
	TOTAL OPPORTUNITY COST PER ANNUM	24000
	COST PER UNIT EFFORT (*c*) = 406000 RMB/trawl/year	
PRICE PER UNIT HARVEST	Avg. Price/kg	20
	Avg. Catch Per Unit Effort	4.387 MT/trawl/year
	1 MT	1,000 Kg
	Per annum Catch in Kg	4387 Kg/trawl/year
	PRICE PER UNIT HARVEST (*p*) = 87740	

*different cost and price values are in RMB (1 USD = 6.71 RMB) necessary to mention that variable cost is calculated for six months because fishing is done only for six months each year. In the other six months fishermen repair their boats, do other business or take rest. The opportunity cost (24000 RMB) was estimated by using minimum wages of labor (4000 RMB per month). For the price per unit harvest (87740 RMB per year), the average per kilogram wholesale price of *S. sinensis* (20 RMB) was used. Estimated average catch per unit effort and catch in kilogram remained at 4.387 MT per trawler per year and 4387 kilograms per trawler per year, respectively.

Discussion

The process of fisheries management starts with data gathering. It proceeds with data analysis, interpretation of results and finally ends with decision making by consulting all the stakeholders[31-32]. The results obtained during the fisheries management process indicate RPs. These RPs by considering current fisheries status are used to achieve management goals such as ecological, biological, economic, social, etc.[33]. The concept of RPs was used for the first time in 1992 during the United Nations Conference on Environment and Development (UNCED). Later on, these points were included in FAO's Code of Conduct for Responsible Fisheries[34-36]. In the science of fisheries management, the most commonly used RP is MSY. MSY is a theoretical concept, which represents the maximum catch quantity of the fish which does not harm the fishery population under normal existing conditions[12]. This RP has received high projection in fisheries management literature in the past and is mostly used for making legislations[33,37].

MSY has the ability to predict the status of the fishery stock. If the computed value of MSY is lower than the reported catch values of a fishery resource, then the fishery stock is assumed to be overexploited. On the other hand, if the calculated value of MSY is higher than the reported catch values of a fishery resource, the fishery stock is believed to be underexploited and has a potential to increase the catch further[38]. Our obtained results, H_{MSY} = 185357 MT, indicate that fishery resource of *S. sinensis* is biologically overexploited in the past as reported harvest of this fishery resources is higher during some years, *viz*., 2005, 2007, 2008 and 2011. However, with respect to the economic harvest, H_{MEY} = 137177 MT, the reported catch of *S. sinensis* during every year is much higher which clearly indicates decreasing profit margin. Moreover, the reported catch obviously signposts ongoing open access regime as H_{OAY} = 185285 MT. It is reported that uncontrolled increase in fishing effort is responsible for overexploitation of fishery resources[39]. CPUE also illustrates the state of the fishery resource. If CPUE shows a decreasing trend with stable fishing effort level, it means that fishery resources are declining. Conversely, if CPUE shows an increasing trend with stable or increase in fishing effort level, it represents that fishery resources are flourishing[33].

This study also finds that although the Chinese government has efficiently controlled an increase in fishing effort in the past few years, however, the fishing effort is still very high. All of our computed efforts levels, i.e., E_{MSY} (35624), E_{MEY} (17462) and E_{OAE} (34924) are significantly lower than reported fishing effort in Shandong, China. Surprisingly, the ongoing effort level is more than double with respect to E_{MEY}. To this end, several studies indicate that fishery encouraging policies in the past resulted in the increase in fishing effort and overexploitation of fishery resources in China[40]. In order to deal with these problems, several efforts made by the Chinese government. For instance, in 1987, single control system was introduced to restrict horsepower by defining quota. Later on, another policy, *viz*., double control was also implemented in 1997 to control horsepower and fishing effort together[27]. Afterward, a ban on fishing boats was imposed to restrict fishing during the summer[41]. To continue with, another effort to reduce fishing effort was made, 2003 – 2010, through fishing boats buyback program[27]. All of these efforts definitely have improved the situation; however, still, fishing effort is too high. It is also reported that in China the fishing vessels are overcapitalized[27].

In addition to MSY, MEY is also used for fishery management particularly when the objective is to increase the profit. Although, MSY is usually used for the biological conservation of the fish stock, however, with some modifications it can also be used for this purpose[42]. MEY confers dual benefit. It not only conserves the fishery stock biologically but also increases the revenue. Thus, most of the time economists prefer this reference point to manage the fishery resources[43]. It represents the level of minimum fishing effort at which the maximum economic revenue is generated[44]. This study finds that revenue at MEY ($\prod_{MEY}$ = 5.01 billion RMB) is much higher as compared to the revenue at MSY ($\prod_{MSY}$ = 1.80 billion

RMB). Thus, operating fisheries sector at MEY can increase the revenue about three times. However, in order to achieve this higher revenue, there is a dire need to reduce the fishing effort which is too high as mentioned earlier. At the end, it is necessary to mention that this study is a preliminary study. In order to manage *S. sinensis* fishery resource biologically or economically further in-depth studies involving long data series and bigger survey are suggested.

Conclusions

This study determines that *S. sinensis* fishery resource is under the state of overexploitation as CPUE is decreasing with the passage of time. The harvest at MSY and OAY is almost the same, which indicates that this fishery resource is experiencing conditions like open access regime. This situation, if not controlled, may lead to more costs and less revenue resulting in the overcapitalization of fishing vessels. The obvious reason for the decline in the catch of *S. sinensis* is high effort levels. Recent effort levels are much higher (42120) than the estimated effort level (35624), which should be at MSY. On the other hand, for MEY this level is more than double. This high effort level is playing a central role in declining the subsequent catch and decreasing profit. Moreover, revenue generated at MEY ($\prod_{MEY}$ = 5.01 billion RMB) is much higher as compared to the revenue generated at MSY ($\prod_{MSY}$ = 1.80 billion RMB) which clearly suggests that operating fishing industry at MEY level will bring a lot of revenue and increased profit margins. However, further comprehensive studies are needed in this regard before making and implementing further fishery management strategies because any change in fishing methods or effort levels, etc., will directly affect this fishery resource and this study is just a preliminary step in this regard.

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Conflict of Interest

Authors declare no conflict of interest.

Author Contributions

YH initiated this work and wrote the article. MM designed, supervised, collected data, and edited this article. MN did data analysis and constructed tables and figures.

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